DEVELOPMENT of a SOLAR POWER SUPPLY

for

REMOTE AQUACULTURE OPERATIONS

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PREFACE

This report presents a summary of the joint Energy, Mines and Resources/SOLTEK Solar Energy Ltd. sponsored development project for a stand-alone solar power system for the aquafarming industry. The intended purpose of this report is to summarize the design of a prototype system, the results of a 6 month monitoring program at a salmon farm and to discuss the economics of solar energy systems for the aquafarming industry.

Since solar energy is not well understood by the public, one of the objectives of the project was to provide a case study which could be cited to prospective users of solar energy systems. In particular, a demonstration project aimed at the aquafarming industry, which has historically high power generation costs, was considered highly useful to marketing alternative energy systems to this group.

Although this report discusses solar energy and its application to aquafarming, the results are useful for anyone considering solar power systems for domestic and industrial loads. It includes a discussion of the benefits of retrofitting an existing generator with a solar array to reduce operating costs, and this is relevant to any genset owner.

ABSTRACT

This report summarizes the results of SOLTEK Solar Energy Ltd.'s development of a stand-alone solar power system for the aquafarming industry. There were approximately 200 salmon farms in British Columbia in 1987, with licences for 50 additional sites approved.

Aquafarms are typically located in remote tidal channels, and over 90% do not have access to grid connected power. At present, diesel generators are the most common source of power, with some farms using small hydro systems or having no power at all.

SOLTEK designed a 12V DC solar power system to deliver a minimum of 600 watt hours per day. The system used a 630 Peak Watt photovoltaic array of 14 45 watt modules, 1540 Amp-Hrs of battery storage, a 50 amp series relay regulator and a 1.2 kW inverter to provide 120 V AC power.

The prototype system was installed at the Goodrich Island Seafarms' Sooke Basin site located 50 km west of Victoria in December, 1986. Insolation and DC power consumption were monitored for the six month period from January 27 to June 1, 1987.

The results of the monitoring program showed that the caretakers living on the Goodrich site used only 445 Watt-Hrs per day, 25% less than the design power budget, showing in general that the system was sized too large for this specific site. From the insolation data available, the prototype system could potentially deliver on the average 1.8 kW-Hrs per day with a winter low of 0.6 kW-Hrs and a summer average of 2.5 kW-Hrs per day.

The present day installed costs of stand-alone solar power are estimated to be $15.40 per Peak Watt, or $18.00 with a 1.2kW inverter. Over a 10 year period, the annual costs for a solar power system supplying a 0.6 kW-Hr/day load are approximately half of a comparable diesel system. An existing diesel supplying the same load can retrofitted with a small solar array, and the subsequent savings in fuel will result in a payback time for the solar system in the order of 4 years.

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EXECUTIVE SUMMARY

Over the past three years, a new industry has emerged in British Columbia. Commercial salmon farming, common in the Scandinavian countries, has undergone a boom in British Columbia with the depletion of natural salmon salmon stocks and a consumer demand for fresh seafood. With thousands of miles of sheltered channels and inlets, and the import of Norwegian technology and investment capital, over 200 aquafarm sites are now established, and many more are under development.

Salmon farmers seek the refuge of quiet, clean and typically remote locations for the farms. But this same seclusion means that conventional grid-connected power is not available, and any power used must be generated on-site. Over 90% of the existing farms must rely on gas or diesel generated power, haul recharged batteries or have no power at all.

The purpose of this project was to explore the potential of solar energy systems in the aquafarming industry. The proposed stategy was to design a stand-alone photovoltaic power supply to meet the projected power requirements of a typical farm, to build and install a prototype system at a local salmon farm and through a monitoring program, evaluate the concept from both a practical and economic perspective.

The prototype system was designed to satisfy a power budget averaging 52 Amp-hrs per day at 12 V DC, and consisted of cabin lighting, radios, automatic fishfeeders and water quality monitoring equipment. The design incorporated sufficient safety margins to accomodate a 7 day period of no-sun as there were no plans for a backup power source at the site.

Using the insolation data available from Nanaimo, B.C., 100km north of the proposed installation site in Sooke Basin, the array was specified to be 630 peak watts to meet the power requirements through the winter months. SOLTEK selected 14 45 peak Watt modules manufactured by Kyocera International Inc.

The battery bank was sized at 1540 Amp-Hrs to provide ample reserve capacity, and to restrict the average depth of discharge to the top 20% of capacity to prolong battery life. The batteries used were 6V golf-cart type deep-cycle batteries. SOLTEK also selected a 50 amp series relay charge regulator and a 1.2 kW inverter to provide 120V AC power at ths site.

The prototype system was installed at the Goodrich Island Seafarm in Sooke Basin, 50 km west of Victoria in December, 1986. In January, SOLTEK installed a DC watt meter and and integrating pyranometer. For the period of January 27 to June 1, 1987 while there were two caretakers living at the Goodrich site, SOLTEK recorded the daily total solar radiation and power useage.

The results of this monitoring program were used to evaluate the system design. It was found that the actual power consumption at the site averaged 37 Amp-Hrs/day, significantly less than the design power budget of 52 Amp-Hrs. This was attributed to financial restraint by the operators of the Goodrich site as they had not installed several anticipated loads including a 12V refrigerator and automatic feeders.

Measured insolation during the 5 month monitoring period was compared with the design data, a 29 year average (1951-1980) for Nanaimo, B.C. of RF1 insolation on a south facing surface inclined at the array plane angle of 60 degrees. The data showed Sooke Basin received 17% less radiation than the Nanaimo average, while a comparison of bright sunshine hours (as RF1 data was not yet available) showed Nanaimo had received 7% greater hours than the norm over the same period. This can be related to the proximity of the hills around Sooke Basin, which frequently attract clouds.

Since the monitoring program revealed that the prototype power system was larger than necessary to satisfy the actual power requirements of the farm, for Goodrich Island Seafarms the system is inefficent and much of the power is wasted. While supplying the average load of 37 Amp-Hrs per day the solar array still maintained the battery bank at a full state of charge nearly 100% of the time.

However, it is of interest to calculate the amount of power that would be available based on recorded insolation and a conversion efficiency of 80%. For the study period, the system installed could have delivered 0.93 kW-Hrs in January and up to 3.1 kW-Hrs in May. Estimated total annual production is in the order of 660 kW-Hrs.

This season to season variability in power production parallels solar availability, and is one of the drawbacks of stand-alone power system design. Through the summer months up to 5 times as much power is available than the winter months.

During the monitoring period, SOLTEK observed the battery state of charge with periodic measurement of electrolyte specific gravity. An experiment showed the low-voltage load disconnect feature incorporated into the charge regulator failed to disconnect until the batteries were 100% discharged, and the threshold voltage was subsequently adjusted to 12.0 V or the 70% discharge level. This feature was designed to prevent damage to the batteries through very deep discharge.

Estimates of daily and maximum battery depth of discharge based on observed solar availability and a constant load of 52 Amp-Hrs/day showed the batteries would not have dropped below 87% capacity. This indicates the battery bank was oversized, and it was concluded that a capacity of 1000 Amp-Hrs would have been sufficient.

Based on historical insolation data for Nanaimo, the stand-alone power system installed at the Goodrich Island farm would produce the following:

minimum daily	0.6 kWHrs
average "	1.8 "
average summer	2.5 "
annual total	660.9 "

The costs for this system were $11,400 including installation, or $18.00 per Peak Watt. The costs without AC power were significantly less at $15.40 per Peak Watt. Over a 10 year period, the annual costs amount to $1,710 as compared to the estimated costs of diesel power at $3,215.00. Small hydro systems are less expensive than solar at $1,325, but have limited application. The conclusion is that stand-alone PV systems are cost-effective against fossil fueled generators despite higher initial costs.

Many existing farms installed generators during the initial building stages. However, retrofitting a generator with a solar array/battery bank is cost effective as well. For example, a diesel operating to satisfy a power budget of 52 Amp-Hrs/day integrated with a five module solar array would have the running time reduced by 90% over the stand-alone generator system. The resulting fuel savings will have a payback time for the solar array of less than four years.

This project has shown that power generation by photovoltaic systems is technically feasible for aquafarms, but also that it is economically viable. The prototype power system was excessively large for the specific site, but this was due to an indefinite power budget at the time of system sizing. For future systems, sizing the battery bank for a reserve of 3-5 days would suffice as the 7 day reserve was found to be excessive. In general all components selected for the prototype system were found to be satisfactory and would be recommended for future systems.

Through this project SOLTEK has developed a power system that offers the aquafarming industry an attactive alternative to generators. During the course of the project, SOLTEK received notoriety from the local press and produced a video which is to be used as a marketing tool to the industry. All of these things have served to educate the public as to the potential of alternative energy systems in their lives.

RESUME

1.0 BACKGROUND

The popularity of stand-alone photovoltaic power systems has been historically restricted by the high capital outlays associated with the initial installation. Despite the many advantages of PV generated power, including almost negligible operating costs, inherent reliability and pollution free power production, it is often difficult to sell a potential user a $10K system to replace a $3K generator even with a demonstrable investment payback period in the order of 5 years. Applications of PV power systems at the present time have been limited to remote locations where landed fuel costs are in the order of dollars per litre or where access is by air transport only.

There is an emerging industry in the coastal regions of British Columbia for whom PV power can be cost-competitive with gas or diesel generated power. The aquafarming industry, with hundreds of salmon and oyster farms established or in the building stages, typically select sites in bays, inlets and channels that are removed from the more populated areas.

Aquafarms raise salmon from fingerlings to market size in nets suspended in the ocean from floats. The farms sell the mature salmon to local and export markets, offering a supply of fresh seafood year round, instead of just a few months during the summer. Realizing a tremendous market potential in British Columbia and around the world, entrepreneurs have boosted the industry from a few sites in 1980 to over 170 existing farms in 1987. An infusion of Norwegian technology and investment money has maintained the growth rate, and over 120 licences for future sites have been granted.

The typical B.C. aquafarm is self-contained, remote and accessable only by boat. They are located in areas that are sheltered from wind and waves, but which have swift tidal currents. A salmon farm will stock between 30,000 and 200,000 fish in pens up to 100 feet square. The fish are introduced to the pens as smolts and grow to 3 to 5 lbs before harvesting, a process taking between 1.5 to 2 years.

With up to $2 million dollars invested in equipment, pens and stock, and danger from waves, predators and poaching, the sites must be manned 24 hours a day. The caretakers live in cabins or trailers on the floats or nearby onshore. The fish are fed either by hand several times a day or continuously by automatic feeders.

Grid connected power is not available to over 90% of existing farms, and at these sites, gas or diesel generators, propane refrigerators and stoves, battery and kerosene lamps and rechargeable car batteries are used. A typical farm would use a 5 kW generator to supply AC power on demand and would run from a few hours a day to 18 hours a day, depending on when the power

was required. In general, battery storage is not used, except for automatic fish feeders, so the generator is used regardless of load size.

The power required to operate a salmon farm is site specific and varies from 0.5 kWHrs to hundreds of kWHrs per day. DC power is used for lights, feeders, electric predator nets and pumps, and 120 V AC power is used for power tools, TV's, stereos and appliances. More elaborate farms might have water pumping systems for transferring feed and fish to the pens.

Solar energy as a power source is very attractive to aquafarmers as the noise, fuel transport and storage problems and maintenance associated with generators can be avoided. However, there is generally a lack of awareness in the aquafarming industry as to the potential of solar energy power systems, and before 1986 there were no PV powered sites.

The purpose of this project was to demonstrate that photovoltaic power is a viable alternative energy source for remote, non-grid connected aquafarms, with an estimated market potential of 150 sites that could benefit from solar energy. The elements of this demonstration included the design of a stand-alone PV power system to meet the specific needs of a local salmon farm, the implementation of this design, and a monitoring program to document system performance, reliability and success at meeting the design goals.

Although this project examines specifically stand-alone PV power, a discussion of the application of solar energy in PV/Genset hybrids has also been included as this is often more practical for larger load sites.

2.0 PROJECT HISTORY

The following summarizes the milestones of the development contract for a solar power supply for aquafarms:

Jan 1986: Seaboy Marine Services Ltd and Project Manager Dave Egles submit a proposal in reply to the RFP issued by the Solar Energy Development Program of Energy, Mines and Resources.

July 1986: Seaboy was awarded a contract by DSS for the Development of a Solar Power Supply for Remote Aquaculture Operations. Contract was divided into two phases: System Design, and Fabrication/Installation & Monitoring.

Aug 1986: Phase I Design Report submitted to EM&R.

Sept 1986: Phase I report accepted and authorization to proceed with Phase II given.
Dave Egles leaves Seaboy to form SOLTEK with partner, Mike Cannon.
SOLTEK and Seaboy apply to DSS to transfer contractual obligations of Phase II to SOLTEK.

Nov 1986: Formal contract assignment completed, SOLTEK begins work of Phase II of contract.

Dec 1986: Fabrication of solar array, power regulation equipment and battery bank begins.

Jan 1987: Array installed on caretaker quarters on site.
Caretaker building wired to accept 12V DC appliances, lights.
Battery bank installed, power system fully operational.
Monitoring begins.

Feb 1987: 1.2 KW inverter installed, 120 V AC power available at site.
Low-voltage experiment begins to test load disconnect, battery protection devices.
Times-Colonist publishes article on Solar Powered Aquafarm in Feb 18 edition.

June 1987: Caretakers move to a nearby farm as Goodrich Island licence sold.
Monitoring program ends.

Aug 1987: Final report submitted.
Video of farm power system produced.

3.0 DESCRIPTION OF THE INSTALLED POWER SYSTEM

3.1 SYSTEM DESIGN

The following sections discuss the goals and the development process of the power system designed in the course of this contract. They are a summary of similar discussions found in the original proposal [1] and in the Phase I Report: System Design [2]

3.1.1 Aquafarm Power Budget

The standard design procedure for stand-alone PV systems begins with a detailed summary of the loads to be powered by the array. The operators of the Goodrich Island farm were asked to predict their power requirements once the farm went into full production. Table 3.1 summarizes their estimated daily power budget:

Appliance	Units	X Current Drain(Amps)	X Duty Cycle (Hrs/Day)	= Avg AmpHr/Day
Fishfeeders	4	2.5	1.0	10.0 AHr/Day
Lights	2	2.1	4.0	16.8 "
	2	1.3	4.0	10.4 "
	1	4.0	1.0	4.0 "
Water Quality Instruments	1	0.2	24.0	4.8 "
VHF Radio	1	0.1	12.0	1.2 "
Television	1	5.0	1.0	5.0 "
Power Tools	(summer only)			
		TOTAL POWER REQUIREMENT		52.2 AHr/Day

TABLE 3.1: Summary of Power Requirements at Goodrich Island Seafarms' Sooke Basin site.

3.1.2 Design Criteria Summary

The following criteria were considered during the design of the solar power system for the Goodrich Island Seafarm:

1. Sufficient power must be available to meet the daily

power requirement of 52 Amp-Hrs year round.

2. The power must be available as 12 V DC for lights, radios and fishfeeders. 120 V AC power must be available on a limited basis for appliances and power tools.

3. Total battery reserve capacity must be sufficient for 3 weeks of operation in the event of a controller/array failure.

4. Power system must be reliable and require little maintenance.

5. Solar panels and electrical equipment must be corrosion resistant and immune to the effects of salt water.

6. The total system costs must be kept to a minimum in order to make the power system marketable.

3.1.3 Design Methodology: Array and Battery Sizing

The size of the solar array required to meet these power requirements was determined through the use of a monthly simulation routine developed by SOLTEK. This routine used the RF1 (Mean Monthly Global Solar Radiation for Each Hour) insolation data for a slope inclined at 60 degrees available from Nanaimo, B.C. (AES, 1986) The model calculated the output of a single panel, and determined the required number of panels to satisfy the power requirements of the Sooke Basin site.

A sample of the simulation routine output has been included as Table 3.2. Note that in the calculation of array size a safety factor of 25% has been included to account for battery cycling efficiencies (typically 80%) and line losses.

To meet the average daily load of 52 Amp-Hrs, an array of 14 modules was selected. Since the power system was designed to be a stand-alone system, with no backup, the array was sized large enough to meet the estimated load through the winter. The array mounting angle of 60 degrees was selected to maximize the winter output as shown in Figure 3.0.

The battery bank size was determined after consideration of daily depth of discharge, minimum reserve capacity and temperature. In order to maximize the battery life, it was desired to limit the maximum depth of discharge to less than 20% battery capacity. Although the manufacturers recommended maximum depth of discharge is to 80% capacity, by cycling the battery in the top 20% of capacity the number of charge/discharge cycles possible over the battery life is greatly increased.

A five day no-sun period was used as a conservative winter estimate of the average time between full charge. This implied

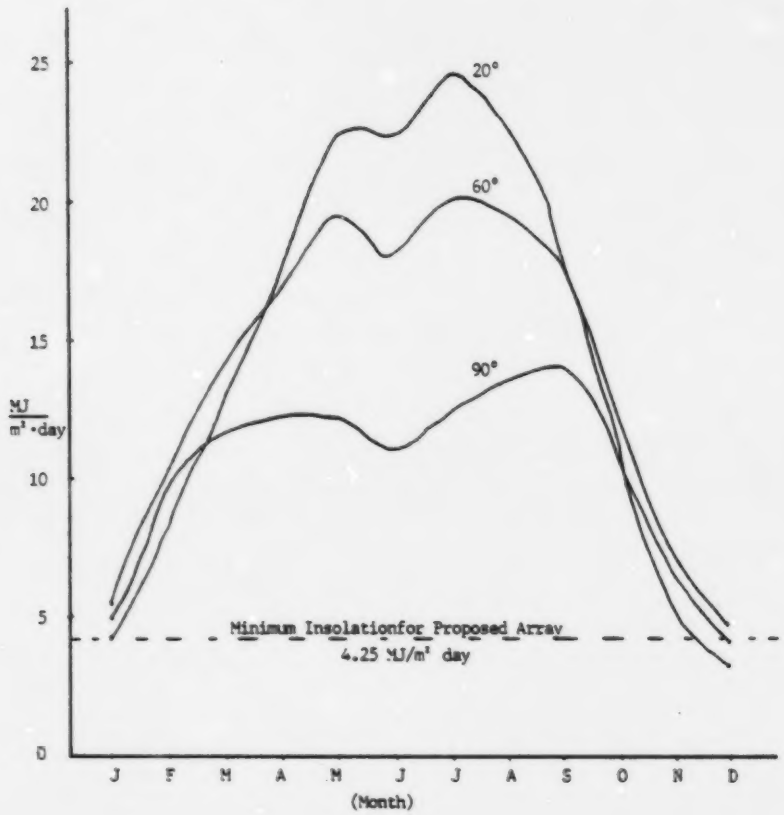

FIGURE 3.0: Mean Monthly Hourly Insolation (RF1) for Nanaimo, B.C. (1959-1980) for 20, 60 and 90 degree angles of inclination.

the battery bank must have a reserve of 260 Amp-Hrs under the average load of 52 Amp-Hrs per day.

To cycle the battery in the top 20% only, the battery bank size was then required to be 1300 Ampere-Hrs. Adding a sufficient safety margin, and to compensate for loss of capacity at the average winter temperatures of 5 degrees Celcius, the capacity was increased to 1540 Amp-Hrs, the unit battery size being 220 Amp-Hrs. This provides a power reserve of 30 days in the event of array failure.

SYSTEM PERFORMANCE SPECIFICATIONS 14 MODULES
****

SOLTEK SOLAR ENERGY LTD.

AQUAFARM SOLAR POWER SUPPLY: SOOKE BASIN SITE

MONTH	INSOLATION MJ/M2	PANEL OUTPUT Amps	ARRAY OUTPUT Amps-Hrs/Day	DAILY LOAD Amp-Hours	PERCENT OF LOAD SUPPLIED
JAN	5.33	0.23	58.30	52.00	112.12
FEB	10.73	0.47	117.37	52.00	225.71
MAR	14.21	0.62	155.43	52.00	298.91
APR	16.90	0.73	184.86	52.00	355.50
MAY	19.06	0.83	208.49	52.00	400.93
JUN	17.88	0.78	195.58	52.00	376.11
JUL	20.20	0.88	220.96	52.00	424.91
AUG	19.76	0.86	216.14	52.00	415.66
SEP	18.00	0.78	196.89	52.00	378.64
OCT	12.18	0.53	133.23	52.00	256.21
NOV	6.83	0.30	74.71	52.00	143.67
DEC	4.53	0.20	49.55	52.00	95.29
		ANNUAL AVERAGE			290.31

NOTES:
1. All figures are per hour based on a 24 hour average
2. Array Size: 630 Peak Watts - 14 Modules @ 70 degrees
3. Array output includes a 25% safety factor to reflect battery cycling and line losses.

TABLE 3.2: Performance Specifications for Aquafarm PV Power System

3.2 AS-BUILT SPECIFICATIONS

This section summarizes the electrical and mechanical design of the system as built and subsequently modified at the Sooke Basin site. Figures 3.1 to 3.4 show various views of the installed power system and its components.

3.2.1 Summary of Power System Components

The following is a list of components used in the fabrication of the power system installed at the Sooke Basin site:

* 630 Peak Watt Array (14 modules @ 45 Peak Watts)
  (Kyocera LA361J45AV Modules)
* 1540 Amp-Hrs Battery Storage (14 220 A-Hr 6 Volt Cells)
  (Trojan T-105 Batteries)
* 1200 Watt 12 VDC - 120 VAC Inverter
  (Heart Interface HF12-1200X)
* 50 Amp Regulator with Remote Temp. Compensation, Load Disconnect, Adjustable Setpoints
  (Specialty Concepts Inc. PPC 12AMP)
* Integrating Pyranometer (Natural Power Inc. S62-11)
* Integrating DC Wattmeter (Natural Power Inc. A40-141)
* 2 @ 15 Watt Fluorescent Lights (Thin-Lite)
* 2 @ 30 " " " " "
* SOLTEK designed array mounting structure, battery enclosure, power distribution box, switches, outlets and wiring.

The specification sheets for the modules, batteries, controller and inverter have been included in the appendix.

3.2.2 Electrical Design

The electrical schematic of Figure 3.5 shows the wiring layout of the installed power system.

The schematic shows the solar array was divided into three segments. This provided redundancy in the connections and facilitated installation. This also served to reduce line losses since each subarray had its own pair of #8 gauge conductors which were connected directly to the regulator. The line losses in the array cables were under 3% with this configuration.

The regulator was connected to the batteries with #4 welding cable. A second pair of conductors connected the load distribution panel to the regulator. This panel had 6 individually fused and switched circuits to which the lights, radio and outlets were connected.

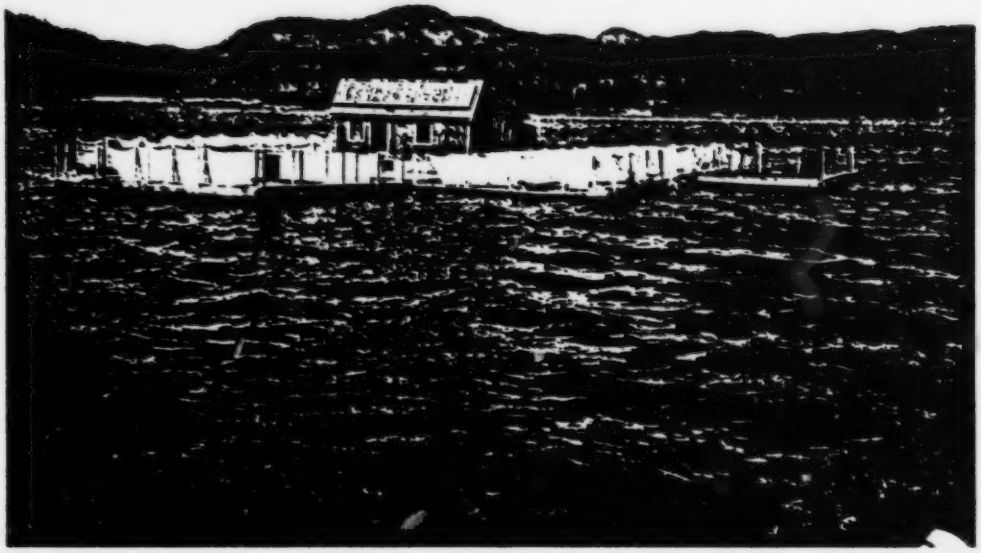

FIGURE 3.1: View of Goodrich Island Seafarms

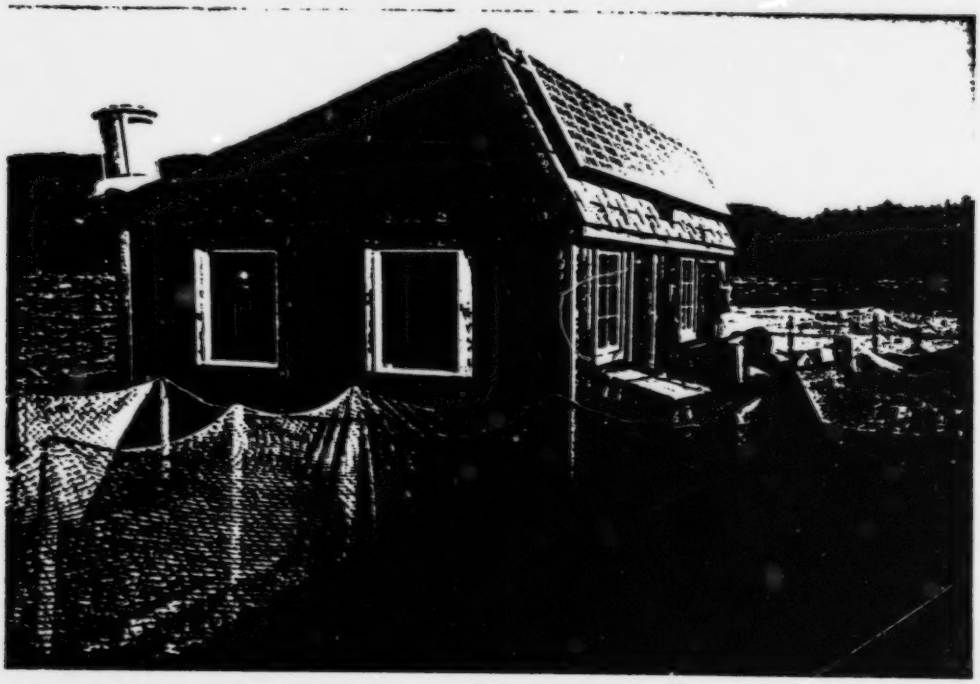

FIGURE 3.2: Mounting angle of Solar Array

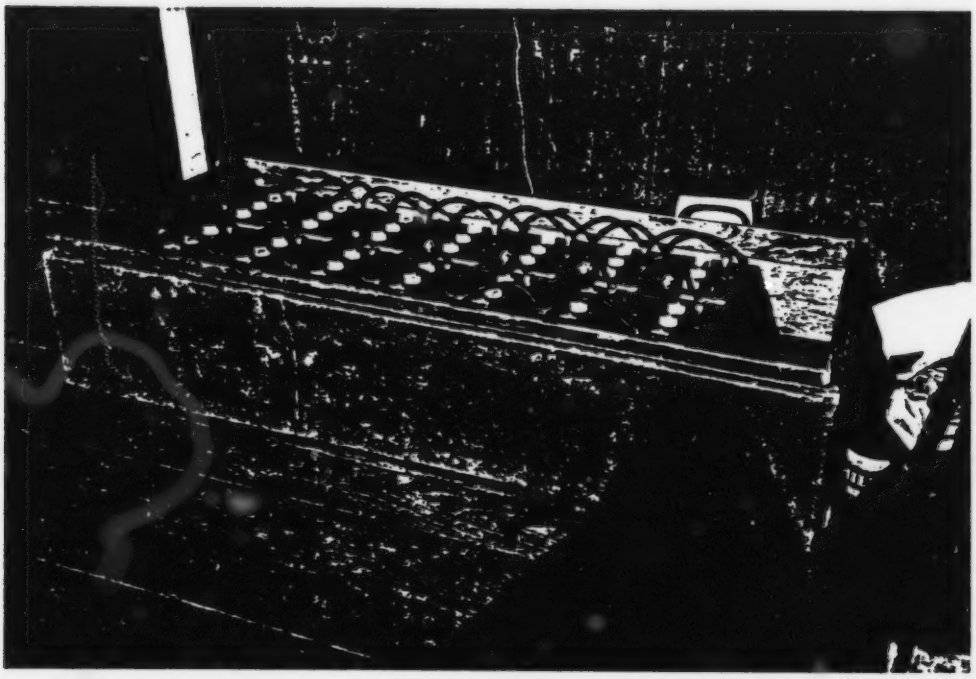

FIGURE 3.3: Battery Bank

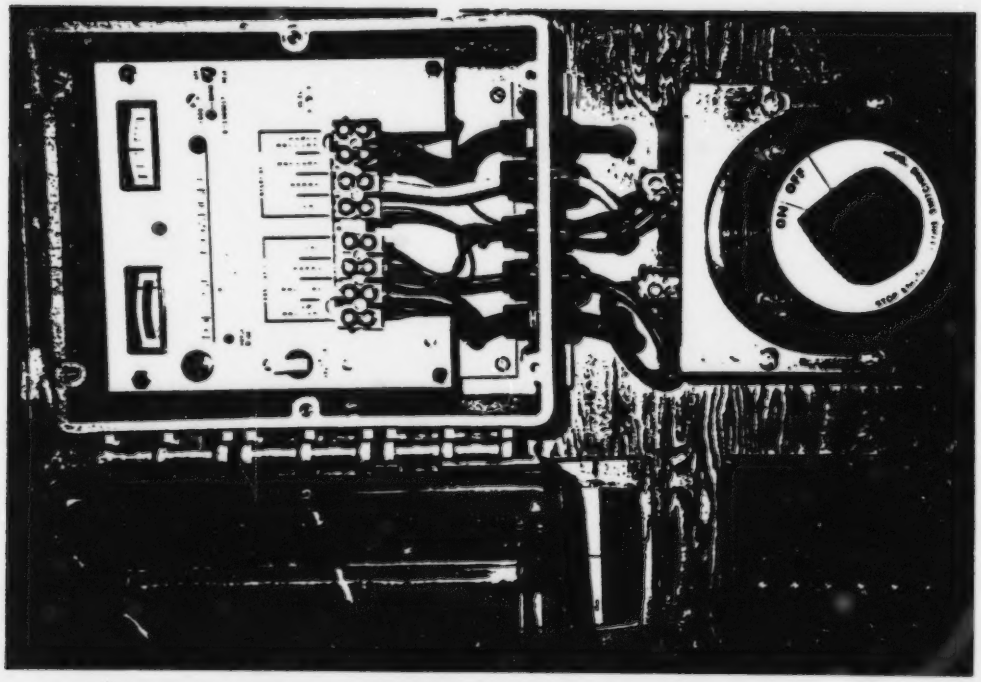

FIGURE 3.4: Charge Regulator

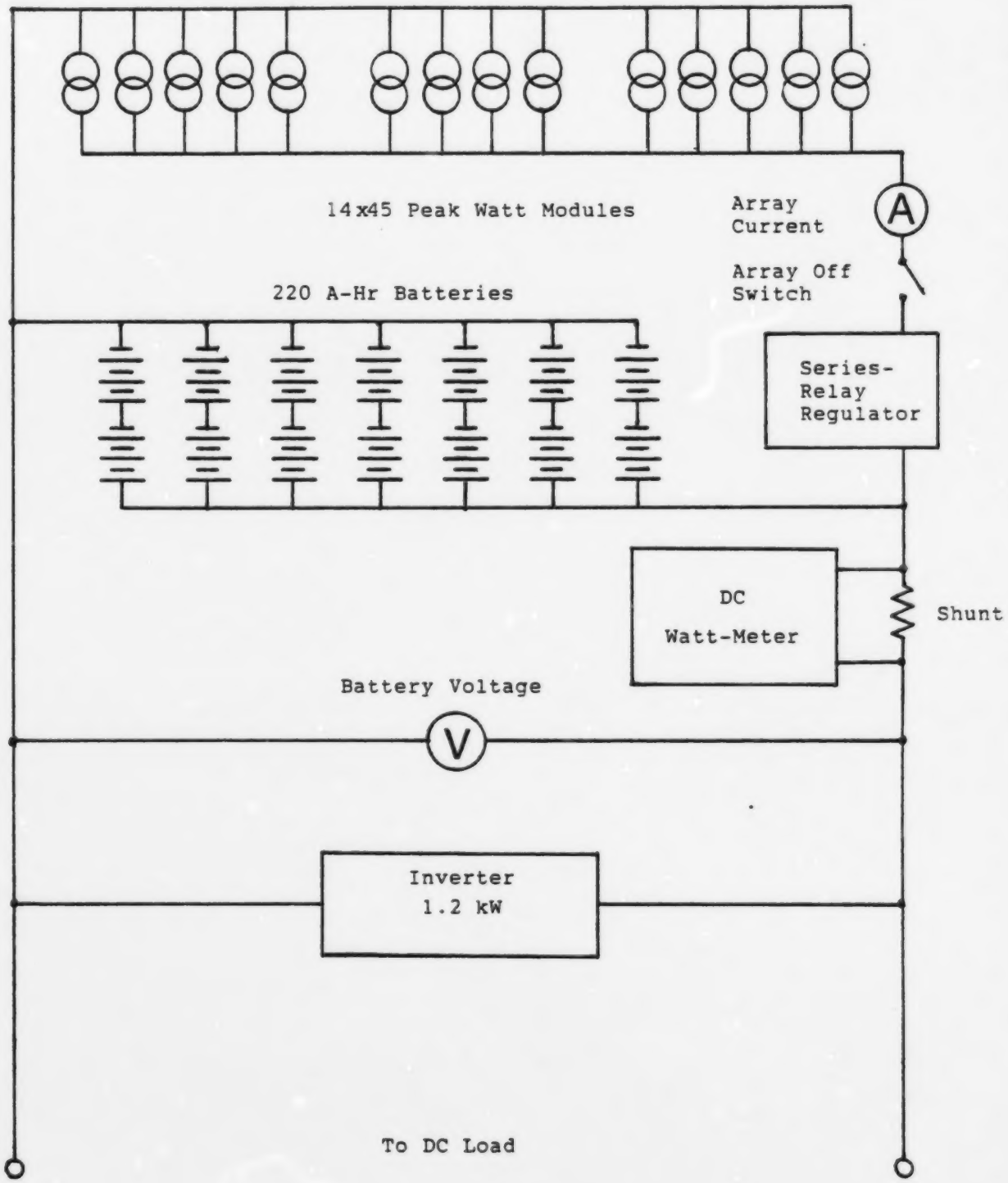

FIGURE 3.5: Electrical Schematic of Power System

3.2.3 Mechanical Design

The mechanical aspects of the power system design were greatly simplified when SOLTEK was allowed to modify the building plans for the caretakers shack on the farm before the building was constructed. Figure 3.1 shows that the south facing slope of the building was pitched at 60 degrees, allowing the array to be bolted directly to the roof without an intricate mounting structure. This was not only the simplest method of attachment but also integrated the array into the site in a way that was the most aesthetically pleasing.

The batteries were located outside the caretakers shack in a fibreglass-plywood laminate box. The box was vented to prevent buildup of hydogen gas which might be released when the batteries reached a full state of charge.

All exterior wiring was lead through 2" plastic conduit.

3.2.4 Power Regulation Equipment

For this system SOLTEK had selected a PPC-12 AMP series-relay regulator manufactured by Specialty Concepts Inc. The regulator is rated for a charge current of 50 Amps, and has a number of features including:

* Temperature Compensation
* Low-Voltage Load Disconnect
* Load Circuit Breaker
* Lightning and Surge Protection
* Reverse Polarity Protection
* Array Current and Battery Voltmeters

3.2.5 Battery Storage

During the construction phase of this contract SOLTEK elected to change the battery type from the specifications of the design report. The recommended Gel-Cell type batteries were replaced with standard heavy-duty "golf-cart" type batteries. Although these batteries have a disadvantage of being wet cells, and are not maintenance free, they are more economical at $0.85 per amp hour as compared to $1.75 for Gel-Cells. The economics of golf cart batteries, and the desire to keep the costs of the prototype system down as a selling point for future systems, led to this decision.

3.2.6 Electrical Power Inverter

SOLTEK selected a Heart Interface HF12-1200X inverter to provide 120 V AC power for appliances and tools at the site. This inverter has a 1200 Watt continuous rating with surge currents up to 30 Amps. The inverter was conveniently located inside the caretakers shack, and connected directly to the batteries. It had internal time-delay fusing for AC output and a switch on the inverter itself was used to turn it on/off. With a 10 Amp rating, the inverter was large enough to power drills, power saws and household appliances.

4.0 PERFORMANCE SUMMARY

4.1 MONITORING PROGRAM

To monitor the success of the Goodrich Island solar power system at producing reliable power, SOLTEK installed two monitoring instruments. An integrating DC Watt-Meter was interfaced with the load distribution panel to measure the amount of power used by the farm and an integrating pyranometer was used to measure the insolation in the plane of the solar array.

These instruments kept a running total of power available and power used, but not daily totals. SOLTEK enlisted the services of the caretakers living on the farm to transcribe the daily values into a journal. Daily entries included insolation, power consumed, battery voltage and a description of prevailing sky conditions. A sample data sheet from the journal has been included in the Appendicies.

Unfortunately, since SOLTEK utilized these human data loggers, there are periodic gaps in the time series data, most often on weekends. Missing daily totals were replaced by the average over the missing interval. The daily errors are not considered significant since the total insolation and power consumed were still recorded and available.

The monitoring program began within 2 weeks of installation and lasted 150 days. The period used for the data analysis presented in this report extends from January 27 to May 24, 1987. Data from the month of June has not been used as the farm was uninhabited for most of this period and the loads on the system were minimal.

4.2 INSOLATION

Insolation data was recorded for two reasons: to verify the validity of the historical data used in the system design, and to determine the theoretical maximum power available from the array during the study period.

The pyranometer used, a Natural Power Model S62-11, measured both direct and reflected radiant energy. Since the sensor was bolted to the array mounting structure it produced an accurate measurement of the amount of energy incident on the array.

The insolation data collected during the study period is presented in Figure 4.1. This figure also plots the monthly averages. Although the daily totals are scattered as expected, the monthly averages are in general 17% less than the design data used, the a 29 year average for a south facing 60 degree inclined surface at Naniamo, B.C.(1959-1980), some 100 km north of the site. Table 4.1 compares the data collected with the Nanaimo

average and shows how 1987 compares with the 29 year average.

Note that the percentages quoted in Table 4.1 relate the hours of bright sunshine observed in the spring of 1987 to the norms; RF1 data was not processed at the time of writing. They show that according to bright sunshine hours, the first 5 months of 1987 average 7% sunnier that the average. Although bright sunshine and total insolation are only loosely correlated, the data shows that the insolation levels at Sooke are in general lower than the design data used from Nanaimo. This is reasonable considering the topography around Sooke, with low hills that attract clouds during the moist times of the year.

	Sooke Data	Naniamo Avg.	Nanaimo 1987
Jan 87	5.40	5.30	- 7 %
Feb 87	8.75	10.75	+ 15 %
Mar 87	9.36	14.21	- 12 %
Apr 87	15.29	16.90	+ 3 %
May 87	17.97	19.06	+ 19 %

TABLE 4.1: Comparison of average monthly Insolation Data collected at Sooke site with historical data for Naniamo (1959-1980) and (1987) in MJ/M^2/day.

4.3 ARRAY OUTPUT

The maximum amount of power available per day from the solar array is of interest since it determines how quickly the batteries can be recharged. This information can be calculated from the insolation data recorded during the monitoring period as the array output under standard conditions is known.

For the SOLTEK power system, the array is most efficient if operated with a load resistance of 2.3 Ohms, corresponding to a peak current of 38 Amps and peak voltage of 16.5 Volts in full sun. Under these conditions, with a full sun of 100 mW/cm^2 at 25 C, the array will deliver 630 Watts of power. A load resistance of 2.3 Ohms would roughly correspond to a discharged battery bank.

Based on the insolation data collected at the site, the hypothetical peak power for the array has been calculated and is shown in Figure 4.2. In this case the power available from the batteries has been scaled downwards by a factor of 20% to include battery cycling inefficiencies (15-20% depending on state of charge, temperature and battery age), line losses (<3%) and

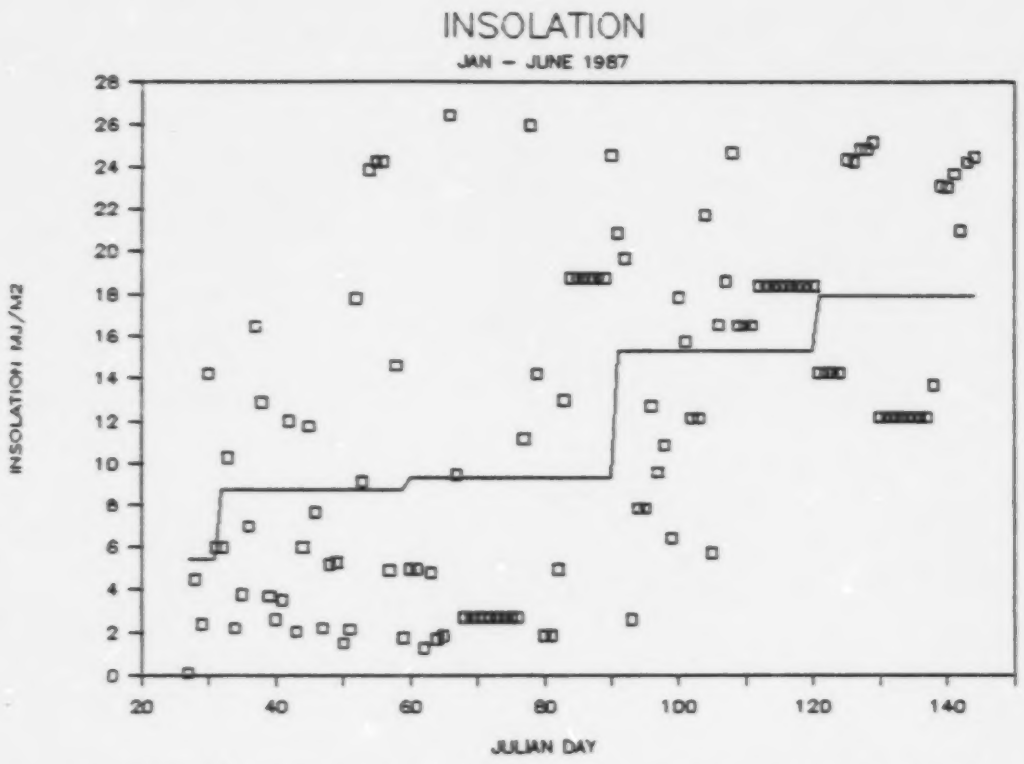

FIGURE 4.1: Measured insolation at Sooke, Jan-Jun, 1987

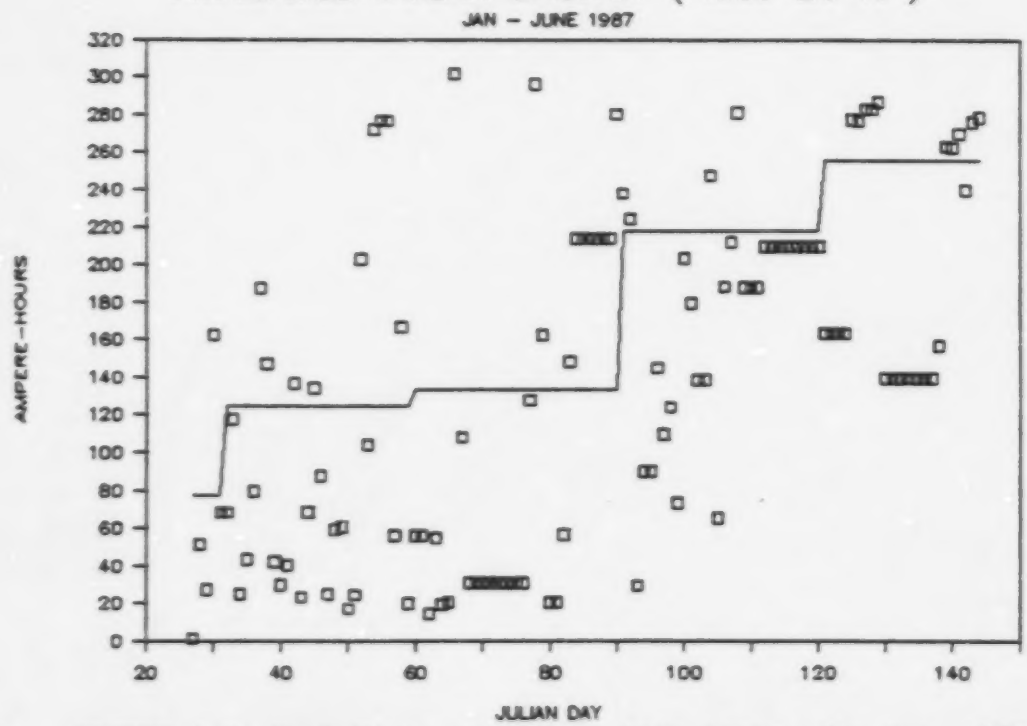

FIGURE 4.2: Peak Power available from array, Jan-Jun, 1987

regulator efficiencies (98%).

Figure 4.2 shows that on the average 175 Amp-Hrs, or 2.1 kW-Hrs, per day were available during the study period. On the worst day 18 Amp-Hrs were possible and on the best day 375 Amp-Hrs. Average availabe power by month as determined from the insolation data are summarized in the following table:

	Amp-Hrs	kW-Hrs
Jan 87	77.5	0.93
Feb 87	124.7	1.50
Mar 87	133.4	1.60
Apr 87	218.0	2.61
May 87	256.0	3.07

TABLE 4.2: Estimated maximum average daily power available per month at Goodrich Island Seafarms site.

4.4 POWER CONSUMPTION

A time series plot of power consumption at the Goodrich Island farm is shown in Figure 4.3. Over the monitoring period the average power used was 53 Amp-Hrs per day. The loads used and their current requirments are shown below:

Appliance	Current
Fluorescent Lights (30 Watt)	2.5 Amps
Fluorescent Lights (15 Watt)	1.3 "
Incandescent Floodlight	4.0 "
Inverter Quiescent Current	0.5 "
VHF Radio	0.1 "
Radio/Tape Player	0.5 "
Incandescent Lights (60 Watt AC)	5.0 "
Television	5.0 "

TABLE 4.3: Current ratings for appliances used at Sooke Site.

Note that the list of appliances used during the study period does not include the fishfeeders nor water quality monitoring equipment that were anticipated at the time of system design. These have not yet been installed by the farm operators due to financial stress within the company.

The jump in power consumption visible in Figure 4.3 during the period of Feb. 21 to Mar. 8 was intentional. SOLTEK instructed the caretakers to use as much energy as possible in order to deplete the battery reserve and cause a load disconnect to occur. The purpose of this experiment was to verify the proper functioning and setting of the adjustable load disconnect, and to observe battery electrolyte specific gravity and voltage as the state of charge decreased.

It was found that by the time the low voltage load disconnect actuated, the batteries were near the 100% discharged level as determined from a measurement of battery electrolyte specific gravity averaging 1.09. The battery voltage at this time was 11.2 volts.

It was obvious that the load disconnect was not offering any protection to the batteries at this setting, so the disconnect voltage was increased to 12.0 volts. This voltage setpoint would prevent discharge of the batteries below 70% total capacity and would serve to prevent deeper discharges from irreparably damaging the batteries.

Although the average power used over the monitoring period was 53 Amp-Hrs, this value is artificially high because of the load disconnect experiment. If data from this period is removed from the calculations, power consumption averages only 37 Amp-Hours per day, significantly lower than the design power budget. The reasons for the lower power usage may be attributed to the following factors:

1. Fewer appliances were installed than originally planned, due to financial constraints on the part of Goodrich Island Seafarms management. These included automatic fishfeeders (at least 5), water quality monitoring equipment and a 12V DC refrigerator.

2. Increasing hours of daylight through the spring, coupled with the caretakers often working from dawn to dusk, meant that less lighting hours were used; as low as 1 hour per day in the summer.

3. Caretaker attitude towards fluorescent lights was not anticipated. The caretaker couple who initially manned the site complained about eye discomfort from the fluorescent lighting and they sometimes resorted to using their own Honda portable generator to supply power for incandescent reading lights (prior to inverter installation).

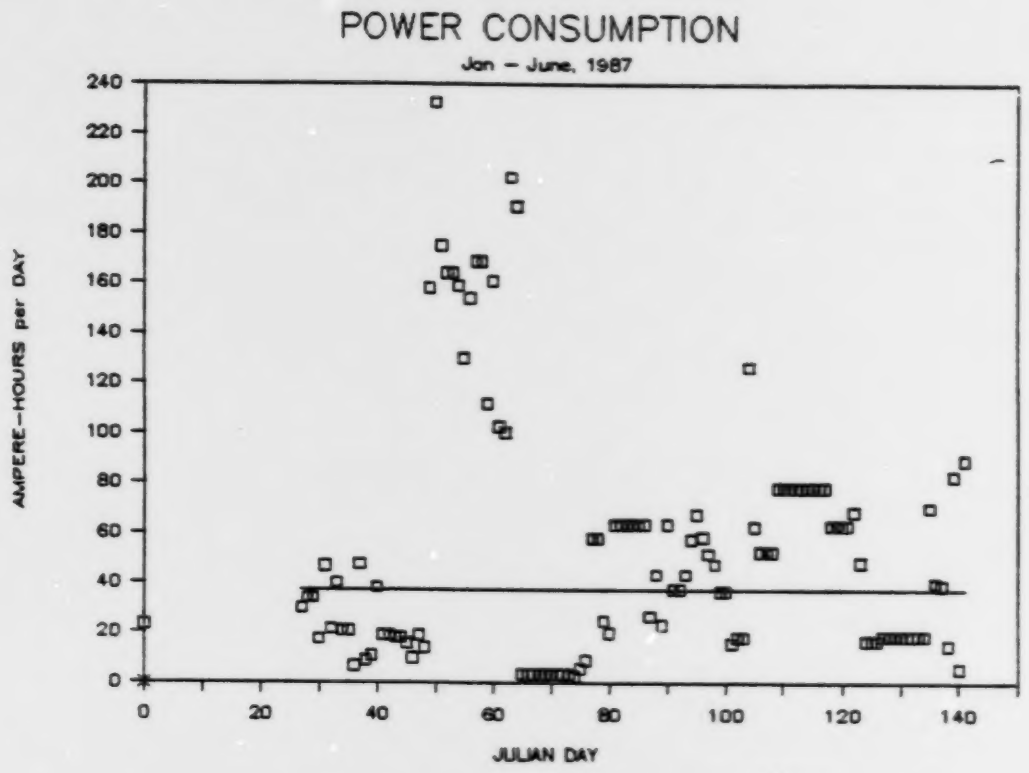

FIGURE 4.3: Power Consumption at site, Jan-Jun, 1987

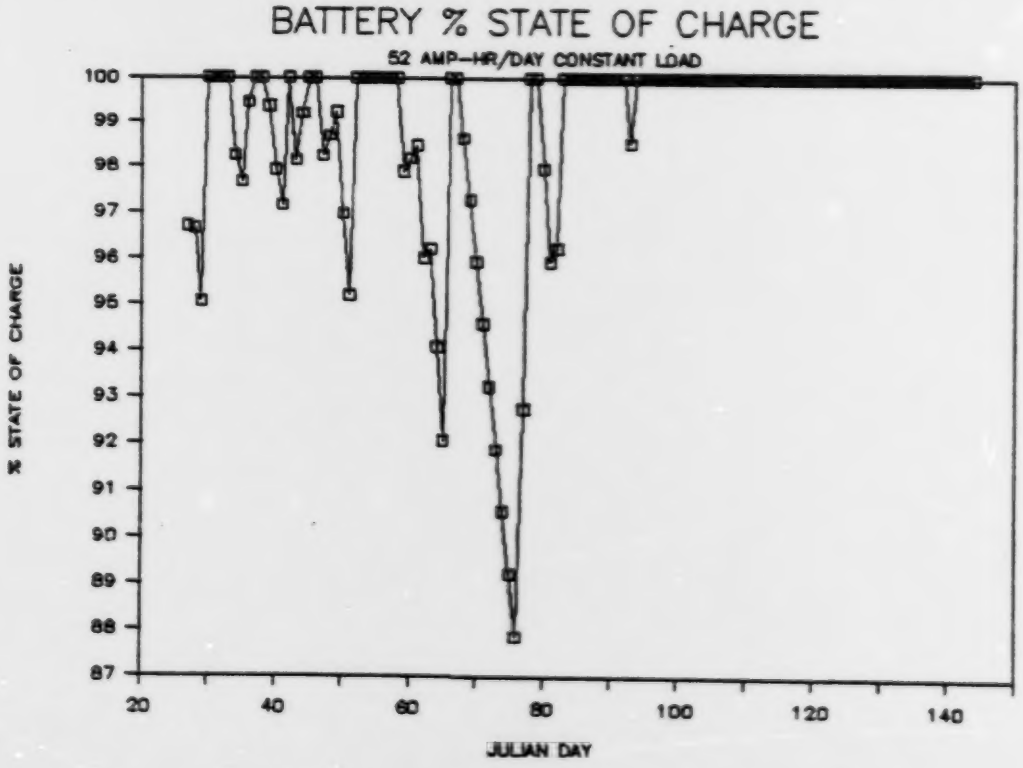

FIGURE 4.4: Battery state of Charge with 52 Amp-Hr. load

4.5 NET POWER PRODUCTION

This section examines the net energy gain or loss on a daily basis to determine the extent of battery cycling during the study period. This is important to evaluate the battery sizing criteria used during the system design.

During the 120 day monitoring period the battery bank was required to supply power beyond that theoretically generated by the solar array on only 6 occassions, excluding the deep-discharge experiment performed in February. The deepest discharge at any one time was 75 Amp-Hrs, indicating that battery capacity was by far in excess of that necessary to supply the farms needs. However, this was partly due to the lower than expected power consumption at the site.

If average loads had been as large as originally anticipated, and were a constant 52 ampere-hours per day, then a net contribution from the batteries would have been required 26 days out of the 120 day period. The maximum discharge would have been 186 Ampere-Hours, corresponding to an 88% state of charge. This still exceeds the design limit of 80% maximum depth of discharge by a large margin. However, it must be remembered that this study began at the tail end of the November to January period when insolation levels are at the lowest.

Figure 4.4 plots the hypothetical state of charge of the battery bank with a constant 52 Amp-Hr per day load. It shows that for a large portion of the time the batteries are not required to contribute to the energy budget of the farm. Based on the insolation data the battery state of charge would have averaged 99% with the increased load.

These results show that for the Sooke site, the battery capacity is probably much larger than necessary. A capacity of 1000 Amp-Hrs would have still remained within the design specifications with a safety margin sufficient to prevent deep battery cycling, even in December. The results also show that designing for a five day no-sun period is a conservative rule of thumb as only once during the trial period did the batteries experience a net discharge for more than three consecutive days.

5.0 DESIGN EVALUATION

5.1 REVIEW OF COMPONENTS

The intent of this short review is to summarize SOLTEK's experience with the major system components incorporated in their aquafarm power supply. Most PV system engineers will be faced with similar component decisions in the course of any power system design. Note that specifications sheets for the major components have been included in the appendix.

5.1.1 Kyocera Modules

There is very little difference in construction, performance or cost in large size modules between the major manufacturers. Kyocera modules were chosen on the basis of price and at the time of purchase were roughly $ 10.00 per peak watt. The modules use polycrystalline silicon solar cells with an efficiency of 11.4% giving a module efficiency of 9.4%. They have anodized aluminum frames and watertight junction boxes, both required in a salt spray environment. The modules were of consistently high quality and the singular problem encountered with them was the crowding of oversized wiring (#8 type SO) into the junction boxes.

5.1.2 Power Regulation Equipment

Regulator selection was one of the most difficult component decisions to make during the system design. By electing to use a single 50 Amp regulator, SOLTEK was limited in options. The SCI regulator was highly recommended by people in the industry, and had many desireable features including low-voltage load disconnect, temperature compensation and two stage charging. At the time, SOLTEK was not able to buy at the OEM level, and the regulator was found to be quite expensive.

There are certain reservations about incorporating a series-relay type regulator in this type of power system because of the long term reliability and Mean Time Between Failure. SOLTEK accidentally disabled the regulator in June when it was installed with the polarities reversed when modifications were made to the load centre. Repairs were made by the manufacturers but the system down time was in the order of three weeks.

In retrospect, a preferable option in power control design would have been to provide two, lower current regulators, and to use shunt type regulators if possible. This would have provided redundancy in the event of regulator failure, and shunt regulators are inherently more reliable.

5.1.3 Battery Storage

SOLTEK's decision to use golf-cart batteries was made on the basis of performance and cost. Golf-cart batteries, at $0.85 per Amp-Hr are one of the most economical deep-cycle batteries available and have been used in photovoltaic installations for the last decade. Their estimated life is 5 years under normal conditions and more if deep-discharges are kept to a minimum. The disadvantages of this battery type are: first, they are wet cells and spillage is a concern during transportation, and second, they require periodic maintenance and electrolyte replacement. They also are subject to damage if frozen, but along the Western coastline this is rarely a problem.

There were no problems with the batteries during the course of the monitoring period except for one cell which failed shortly after installation. Battery specific gravity was measured frequently, but it is expected that several years of use are necessary before any detectable degradation will occur.

5.2 SYSTEM SIZING

One of the goals of this project was to demonstrate the potential of solar energy as a power source in the aquafarming industry. This demonstration included installation of a prototype system at a farm and over a reasonable period showed that it could meet the power needs of the farm.

The results of the monitoring program summarized in Section 4 show that the solar power system was more than capable of supplying the power required by the farm, and would also support an expansion of the power budget by a large amount. They also show that, in this particular case, the array and battery banks were sized in excess of what would have been sufficient to meet the power needs. This was due to a desire to be conservative in the initial design until more experience had been gained with the reliability of stand-alone PV power, and because the actual power needs of the farm were less than anticipated.

The experience has shown several things:

1. In order to build the most economical (and hence the smallest) stand-alone power system the power requirements must be defined more accurately.

2. While cycling the batteries within the top 20% of capacity (but still allowing for the occasional deep discharge) is a positive design strategy, sizing the capacity for 3-days of reserve in the event of no-sun while still remaining in the top 80% of capacity would be acceptable based on the trial period. For the Sooke site, this would halve the battery bank size and reduce the power system costs by 7%.

3. In a stand-alone system, designing for the winter

conditions results in a large surplus of power in the summer. Options of array power diversion when the batteries are charged, such as pumping water, aeration devices or other non-essential loads should be presented to operators as an added benefit.

This demonstration project has shown that a solar power system can meet the power needs of most aquafarms, and that the SOLTEK design and equipment selection are satisfactory. The next section will discuss the economics of stand-alone PV power as opposed to genset or small hydro power generation for the aquafarming industry.

6.0 COST ANALYSIS and COMPARISON WITH ALTERNATIVES

6.1 STAND-ALONE PV POWER SYSTEM COSTS

To compare the costs of electrical power generation at remote sites such as aquafarms, we must define a particular power requirement and examine the costs of supplying this power using the available alternate energy sources.

In this discussion, the hypothetical power budget we are trying to satisfy will be that of the Goodrich Island Seafarm, and the comparison will include options of small scale hydro and diesel generators with battery storage.

The stand-alone PV power system installed at Sooke will produce the following:

minimum daily	50	Amp-Hrs	or	0.6	kWHrs
average "	151	"	"	1.8	"
average summer	210	"	"	2.5	"
annual total	55080	"	"	660.9	"

TABLE 6.1: Output of 630 Peak Watt PV Power System at Sooke

The estimated hardware and installation costs of this PV system are summarized in Table 6.2:

630 W Array: 14 Modules @ $10.00/PW	$ 6,300.00
Mounting Structure	400.00
Batteries: 800 AHr @ $1.00/AHr	800.00
Regulator, Power Boxes	1,000.00
Wiring	200.00
1.2 KW Inverter	1,700.00
Total Hardware Costs	$ 10,400.00
Installation Cost	1,000.00
Installed System Cost	$ 11,400.00

TABLE 6.2: Stand-Alone PV Power System Cost Summary

From this table it can be seen that the installed costs of stand-alone PV power at an aquafarm are $ 11,400.00 or $ 18.00 per peak watt installed. Note that this includes AC power supplied by a high quality inverter. The installed cost per watt without AC power would be substantially lower at $ 15.40.

If these costs are amortized over a ten year period at a rate of 15% per year to include financing, the annual costs of

power generation will be $ 1710 per year. The annual maintenance and operating costs for stand-alone PV power systems are negligible.

With a total annual power production of 660 kWHrs, the cost per kWHr over the 10 year period is $2.60 on the basis of a constant dollar value. Since the entire costs of PV power generation are capital costs, if inflation is taken into account at an annual rate of 10%, then the costs of power drop to $1.70 per kWHr. These costs will drop even further in comparison to conventional power generation equipment if the Class 34 Capital Cost Allowance is applied. Class 34 allows the corporation to depreciate 100% of the solar power system installed costs in the 3 years following purchase, rather than a declining balance basis of 20% per year.

The annual operating costs of a PV system, being almost nil, are one of their most attractive features. Annual maintenannce would include inspection of batteries and replacement of electrolyte, and general inspection of the system. This can easily be performed by the caretaker staff at the site. The batteries can be expected to last 10 years if the number of deep discharges are kept to a minimum. One of the design features of the power system built as part of this project was to protect the batteries from premature exhaustion, and a 10 year life expectancy is theoretically quite reasonable. However, this will not be verifible until 1996.

The only components prone to failure are the power regulators, which can be replaced for under $500.00 including labour. The remaining components have an expected life span of 30 years.

Before a cost comparison will be made between PV power and genset/small hydro power there are a few advantages to solar energy systems that transcends dollar for dollar comparison. These are listed in below:

1. No site preparation as arrays in the order of 1 kW fit easily on existing structures on the average aquafarm.
2. Noise free power generation.
3. No fuel storage problem including danger from spills or fire.
4. No maintenance
5. Power system is easily expandible.
6. 30 year life of array.

6.2 ALTERNATIVE POWER SOURCE FOR AQUAFARMS

The alternative energy sources used at existing aquafarms not connected to the grid include diesel, gas and propane gensets and small hydro systems. Wind energy systems have not been used

to date.

A comparison of the costs and features of each of these alternatives has been made in Table 6.3. The relative advantages and disadvantages of each of these has been summarized in Table 6.4.

These tables show that while small hydro clearly has the advantage of being the lowest cost technology available, the applications are limited to sites where streams of sufficient head and volume are located close to the farm itself. However, most sites are located several hundred feet from shore, making small hydro impractical.

Diesel generators are by far the most popular power source used at aquafarms. Diesel gensets are readily available, and the technology is well understood by farm operators, a factor that at present has limited the incorporation of PV power systems. A genset that is used to charge batteries is less common as most farmers will use the generator whenever power is required, regardless of load size. This is partially due to the haste in which the aquafarms were established, as very little planning went into the power systems selected for the sites. Now that the farms have been in operation a few years, the operators that SOLTEK has interviewed have expressed a dissatisfaction with their present operating mode and are looking for ways to reduce noise, fuel consumption, and in general, generator running time.

From the standpoint of cost, PV generated power is considered competative with diesel for small loads up to 15 kWHr per day. (Post, H.N. and Thomas, M. G., 1987). As shown in Table 6.3, for the aquafarm power budget averaging 0.6 kWHr per day, PV systems are definitely competitive, given the long term operating costs of diesel.

However, PV systems also have their limitations in the aquafarming industry, and these must be considered by the operators before the approriate technology is selected. PV systems are limited in output, and if a large amount of power is required over a short time a backup may be required. For example, some farms may need to use large power tools during the expansion phases, and a PV system with a 1.2 kW inverter will not be able to run a table saw. Some farms have fish hatcheries, and water must be heated, another load that PV power will not practically support.

The solution in these cases may be to incorporate a PV/Diesel hybrid at the site, with the array supporting the common loads, and the generator used to supply AC power for high current appliances. Since most existing farms have a generator, a hybrid system is a natural solution. The solar array can be appropriately downsized as safety margins incorporated in the design are not necessary when a backup power source is available.

The cost-effectiveness of retrofitting an existing generator

with a solar array depends on the extent of the reduction in annual operating and maintenance costs. Since the present use of generators is very inefficient, and battery storage is not normally used, a small array with batteries is an attractive option to aquafarms.

The cost benefits of the conversion of a hypothetical site with an existing 3.0 kW diesel genset with battery storage has been explored in the example of Table 6.5. This example shows that a small array of 5 panels is sufficient to reduce the generator running time by 90% over the stand-alone generator system. For this generator, a 3.0 kW diesel, the reduced running time would mean a direct saving in fuel of $985 per year, and a savings in maintenance costs of $ 450. The net savings of $1435 per year would result in a payback period of this 5 panel system of less than 4 years.

This discussion has shown that above and beyond the inherent benefits of using solar energy power systems listed in Section 6.1, there are definite cost advantages in either stand-alone or hybrid systems.

POWER SOURCE	CAPITAL COST	INSTALLATION COSTS*	ANNUAL O & M COSTS	SERVICE INT.	TOTAL ANNUAL COSTS**
Stand-Alone PV Power	$ 10,400	$ 1,000	$ nil	60 mos.	$ 1,710.00
3.0 kW Diesel w/ 800 AHr Battery Storage, Autostart, Fuel Tank	$ 8,000 Gen 800 Batts	$ 2,000	$1,095 fuel 500 maint. (2.0 l/Hr x 2 Hrs x $0.75/l delivered x 365 days)	6 mos.	$ 3,215.00
Small Hydro w/ 800 AHr Battery Storage, 1.2 kW Inverter	$ 4,000	$ 1,500	$ 500 maint.	2 mos.	$ 1,325.00

* Installation costs include power system delivery to Sechelt area, site preparation and complete installation including wiring.

** Total Annual Costs = (Capital Cost + Installation Cost) x 0.15 (10 year amortization rate) + Annual Operation and Maintenance Costs.

TABLE 6.3: Comparative costs of electrical power generation for aquafarms

SOURCE	LIFE	ADVANTAGES	DISADVANTAGES
Photovoltaic Power System	Array - 30 years Batts.- 10 " Elects- 10 "	Reliable Minimum site prep. No operating/maint. costs. 30 year life of array.	Seasonal Variation in output. High capital costs
Diesel Genset	Gen. - 15 years Batts - 10 "	High output Proven technology Fuel readily available	Operating costs Reliability Noise & fuel pollution Extensive site prep. required.
Small Hydro	Gen. - 5 years Batts - 10 "	Low installed costs High output	Limited applicability Mechanical system

TABLE 6.4: Comparison of relative advantages/disadvantages of alternate power sources for aquafarms.

SYSTEM PERFORMANCE SPECIFICATIONS PV/GENSET HYBRID
****

SOLTEK SOLAR ENERGY LTD.

AQUAFARM SOLAR POWER SUPPLY

MONTH	INSOLATION MJ/M2	PANEL OUTPUT Amps	ARRAY OUTPUT Amp-Hrs/Day	DAILY LOAD Amp-Hrs	PERCENT OF LOAD SUPPLIED	GENERATOR HRS NO ARRAY (per month)	GENERATOR HRS WITH ARRAY (per month)
JAN	5.33	0.24	21.75	52.00	41.82	62.00	22.69
FEB	10.73	0.49	43.78	52.00	84.19	56.00	6.16
MAR	14.21	0.64	57.98	52.00	111.50	62.00	0.00
APR	16.90	0.77	68.96	52.00	132.61	60.00	0.00
MAY	19.06	0.86	77.77	52.00	149.55	62.00	0.00
JUN	17.88	0.81	72.95	52.00	140.30	60.00	0.00
JUL	20.20	0.92	82.42	52.00	158.50	62.00	0.00
AUG	19.76	0.90	80.62	52.00	155.05	62.00	0.00
SEP	18.00	0.82	73.44	52.00	141.24	60.00	0.00
OCT	12.18	0.55	49.70	52.00	95.57	62.00	1.73
NOV	6.83	0.31	27.87	52.00	53.59	62.00	18.10
DEC	4.53	0.21	18.48	52.00	35.54	60.00	25.14
		ANNUAL AVERAGE	56.31	52.00	108.29	730.00	73.82

Notes: 1. Generator with 40 Amp charger (typical)
2. Running time for 52 Amp-Hr/day load = 2 hrs per day
3. Array size 235 Peak Watts, 5 modules @ 47 Watts each.
4. Array output includes a 25% safety factor to reflect line losses, battery charging efficiency etc.

TABLE 6.5: Reduction of generator running time with addition of solar array

7.0 CONCLUSIONS

The purpose of this project was to demonstrate that photovoltaic power systems are practical and viable for specific applications such as remote aquafarms. Practically, the prototype system that SOLTEK designed for this demonstration was more than successful at delivering the power required at the Goodrich Island Seafarm site in Sooke basin, although the monitoring period did not include the worst part of the winter through December and January. Viability was shown through the analysis of installed system costs and annual total costs, which when amortized over a ten year period are approximately half of diesel capital and operating costs.

Analysis of the data collected during the monitoring period highlights improvements that could be made in the SOLTEK design process. Applicability of available insolation data to a specific site design is always a concern, particularily in the mountainous coastal regions where the frequency of cloud and fog is determined by the local topography. In this project, the average insolation in Nanaimo appears tc be in the order of 20 % greater than received in Sooke Basin. Although this cannot be verified until Environment Canada publishes the monthly Radiation Summary for the January to June, 1987 period, for future systems, incorporating a safety margin to compensate for spatial differences in insolation is recommended.

The monitoring program revealed that the power consumption at the Goodrich Island Seafarm was 25% less than the anticipated power budget. This was due in part to fiscal restraint which limited the number of loads installed at the site. The net result is that the power system installed for Goodrich farms was sized excessively large, and could have been scaled down by a factor of one third.

The battery sizing criteria was also found to be excessive. For future systems, a reserve capacity for 3-5 days of no-sun rather than the 7 day reserve is recommended. For this system, 1000 Amp-Hrs would have been sufficient.

This project demonstrated that solar energy is an attractive alternative to generators for the aquafarming industry. However, in order to succesfully market solar energy to fishfarmers, it is necessary to deliver this message to the industry. With the aid of the media attention this project has received, the video produced as part of this contract and future information seminars to potential users, SOLTEK is actively endeavoring to educate this industry about the potential of solar energy systems.

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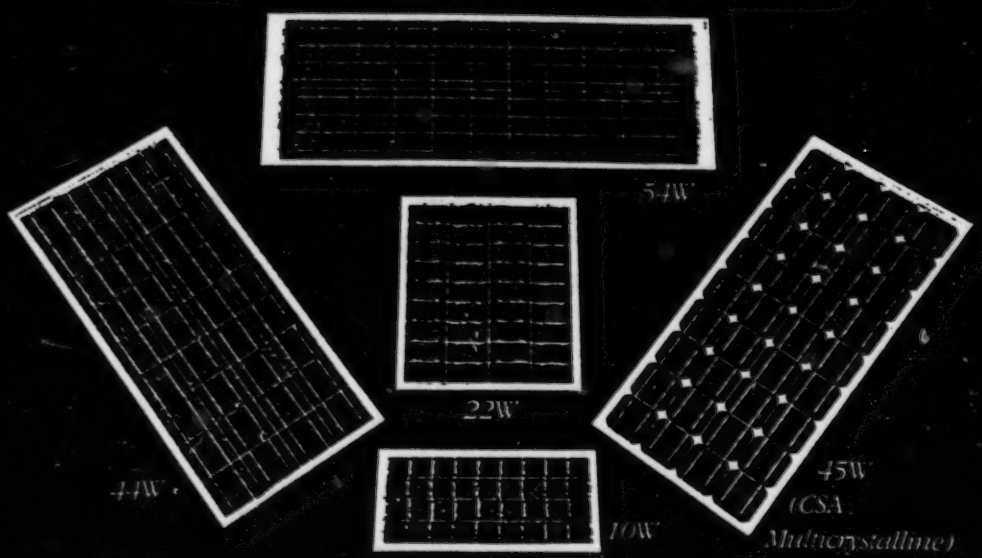
APPENDIX

KYOCERA POLYCRYSTALLINE PHOTOVOLTAIC MODULES



Kyocera, a world leader in solar energy systems, produces polycrystalline photovoltaic modules for a wide range of high-efficiency applications.

The modules use square-shaped wafers made from polycrystalline castings. The square shape of the wafers eliminates space losses typical of round wafers, making the module more efficient in less area. The Kyocera photovoltaic cells attain an efficiency of 12.5%.

The solar cell assembly is encapsulated between tempered glass and a tough back sheet with a transparent pottant, to protect the module against severe environmental conditions.

Applications

Remote homes
Lighting for signs and parking lots
Communications stations
Remote water pumping systems

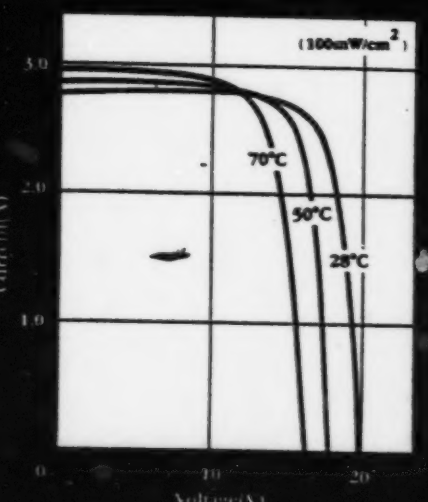


Figure 1. Electric voltage current characteristics for PSA 100H-36H

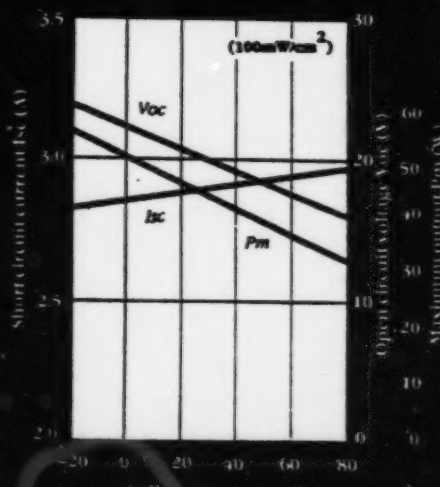


Figure 2. Temperature dependence of PSA 100H-36H output

Specifications

Electrical Characteristics

Model	Peak Output (Pm) (W)	Operating voltage (Vm) (V)	Operating current (Im) (A)	Open circuit voltage (Voc) (V)	Short circuit current (Isc) (A)
PSA 100H-441	54	20	2.7	25.0	2.9
PSA 100H-361H	44	16.5	2.67	20.0	2.9
PSA 50H-361H	22	16.5	1.33	20.0	1.45
PSA 5050-361	10	16.5	0.61	20.0	0.70

Cell temperature: 28°C Insolation:100mW/cm^2 Air Mass 1.5

Module Dimensions

Inches (mm)

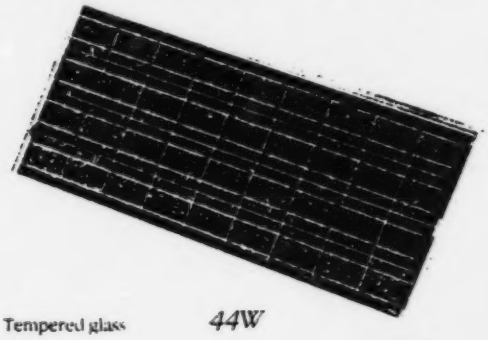
Item	Dimensions
PSA 100H-441	17.5 × 47.9 × 2 (444 × 1216 × 50)
PSA 100H-361	17.5 × 37.8 × 1 (444 × 961 × 26)
PSA 50H-361	17.5 × 20.1 × 1 (444 × 511 × 26)
PSA 5050-361	9.6 × 20.1 × 1 (244 × 511 × 26)

Weight

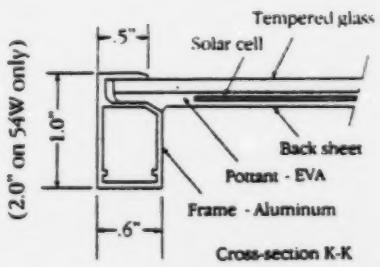
Pounds (kg)

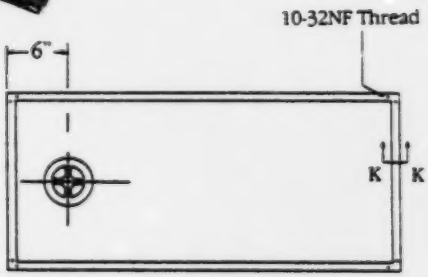
Item	Weight
PSA 100H-441	17.6 (8.0)
PSA 100H-361	12.5 (5.7)
PSA 50H-361	7.1 (3.2)
PSA 5050-361	4.1 (2.0)

Warranty: Kyocera modules are guaranteed to perform within 7% of their rated output over a period of five years.



44W





KYOCERA

Kyocera International, Inc. • **Solar Systems Division** • 8611 Balboa Avenue • San Diego, California 92123 • (619) 576-2600
Kyocera Corporation • 5-22 Kita, Inoue-cho, Higashino • Yamashina-Ku, Kyoto 607, Japan • (075) 592-3851

We reserve the right to modify these specifications without notice

MS5H/84

Photovoltaic Power Control (PPC) SCI

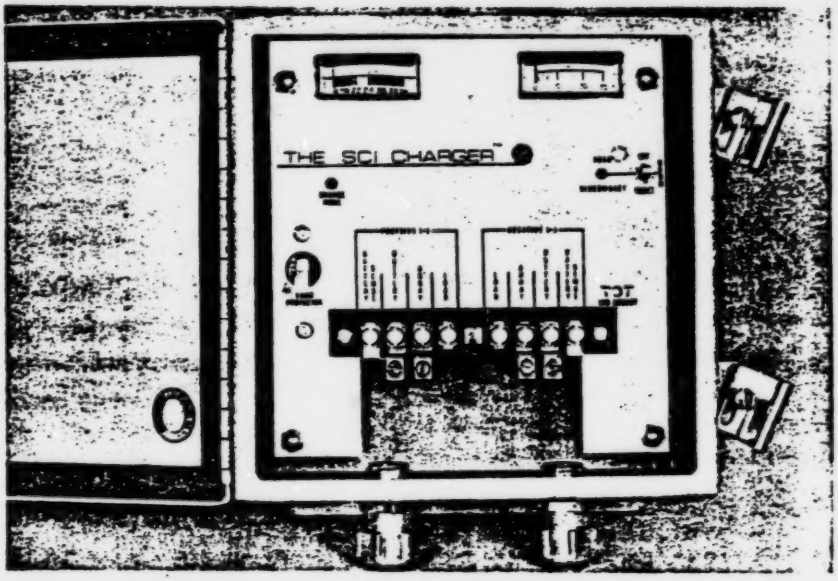
DESCRIPTION

The PHOTOVOLTAIC POWER CONTROL (PPC) is a versatile, industrial quality controller for the efficient use of photovoltaic energy and the protection of expensive batteries. It is available for 12, 24, 36 and 48 volt systems with models for 30 or 50 amps of charge current.

The PPC consists of a series-relay battery charge regulator with low voltage load disconnect, a load circuit breaker, system status lights and metering. The lights indicate "Charging" and "Load Disconnect" conditions and the meters monitor battery voltage and charging current, providing system status information at a glance. The PPC is housed in a waterproof enclosure and has a terminal block with adaptors for up to 6 gauge wire.

FEATURES –

- Two-step charge regulation (12 and 24 volt)
  Single-step charge regulation (36 and 48 volt)
  Colored scale volt meter
- Charge current meter
- Adjustable low-voltage load disconnect with reset/disable switch
- Load circuit breaker
- Status lights
- Waterproof enclosure
- Remote battery voltage sense
- Maximum array usage
- Reverse leakage protection
- Noise protection
- Lightning protection
- Reverse polarity protection
- Central wiring
- Many options



OPERATION

(12 and 24 volt units)

CHARGE REGULATION - The two-step control circuit regulates the charging of storage batteries by monitoring battery and array voltage. At sunrise, when array voltage rises, the charging relay energizes and closes, connecting the solar array directly to the batteries and lighting the "Charging" Light Emitting Diode (LED). The battery will accept as much current as the array will provide, and battery voltage will rise. This is the constant-current (bulk) charge mode and is the first of the two-step charging sequence. When the batteries reach the full charge termination threshold, the charging relay will open and the "Charging" LED will go out. At this point the float regulator takes over to keep the battery below the float voltage and supply limited current (maximum float current) to the batteries. As the battery approaches the float voltage, the current will taper off, eventually falling to the battery's maintenance current. This is the constant voltage (float) charge mode and is the second charging step.

MAXIMUM ARRAY USAGE - If a load is applied when the charger is in the float mode, the regulator will supply up to its maximum float current to maintain the battery charge. If the load is less than the maximum float current the batteries will still be receiving a net charge from the float regulator. If the load current is more, the battery will supply what the float regulator cannot and the battery voltage will fall. When it falls below the full charge resumption threshold, the charging relay will reclose, reinitiating the full charge mode. This insures that if a large load is applied during the day, maximum use will be made of the power available from the array.

CURRENT COMPENSATED LOW-VOLTAGE DISCONNECT - The low-voltage disconnect (LVD) of the PPC prevents damage from over discharge of the batteries by automatically disconnecting the loads. The disconnect threshold is load current compensated by a factor of 10 mv/amp, and a minimum time delay of 3 seconds is applied, to prevent false disconnects. When disconnect occurs, the load relay is energized and opens, and a red LED, visible on the front panel, will light to indicate that the loads have been disconnected. Normal battery charging will continue. At the reconnect threshold the loads will automatically be reconnected and the red LED will go off. The LVD function has a reset/disable switch and user adjustable set points.

REVERSE CURRENT PROTECTION - Ten hours after sunrise the charging relay will open and stay open if the battery is no longer charging. If the battery is still charging, the relay will reclose and open again every hour to determine if power is still available from the array. This guarantees that the relay will be open every night, preventing reverse leakage current without cycling the relay during the high current part of the day or using an inefficient blocking diode.

The operation of a 36 or 48 volt unit is identical with the exception that no float circuit is included.

PPC SPECIFICATIONS

NOMINAL VOLTAGES

PARAMETERS	UNITS	12v	24v	36v	48v
Charge Current, Max (1)	(Amps)	30	30	30	30
Load Current, Max	(Amps)	30	20	15	15
Array Voltage, Max Voc	(Volts)	22	44	66	88
Operating Temp Range (2)	(°C)	0 to 50	0 to 50	0 to 50	0 to 50
Storage Temp Range	(°C)	-55 to 85	-55 to 85	-55 to 85	-55 to 85
Quiescent Current (3)	(Milliamps)	18	18	28	28
Current Consumption, Charging (4)	(Milliamps)	168	168	100	100
Current Consumption, Load Disconnected (5)	(Milliamps)	148	108	90	90
Full Charge Termination (6)	(Volts)	14.8 ± .2	29.6 ± .4	44.4 ± .6	59.2 ± .8
Full Charge Resumption	(Volts)	12.5 ± .2	25.0 ± .4	37.5 ± .6	50.0 ± .8
Adjustable Load Disconnect Range (7)	(Volts)	11.5 ± .5	23.0 ± 1.0	34.5 ± .5	46.0 ± 2.0
Load Reconnect Span	(Volts)	1.5 ± .3	3.0 ± .6	4.5 ± .9	6.0 ± 1.2
Float Voltage	(Volts)	14.1 ± .2	28.2 ± .4	NA	NA
Float Current, Max	(Amps)	3	1	NA	NA

(1) 50 amp option is available.
(2) Operating temperature range may be extended to -20°C to 50°C on special orders.
(3) Both relays unenergized, meters operating, red L.E.D.s off, typical value.
(4) Charge relay energized, meters operating, red L.E.D. on, typical value.
(5) LVD relay energized, meters operating, red L.E.D. on, typical value.
(6) Set points may be specified for nickel cadmium batteries or other special applications.
(7) Decreases by 10mv for every amp of load current.

PART NUMBERING KEY

EXAMPLE:

Model
Voltage
Options

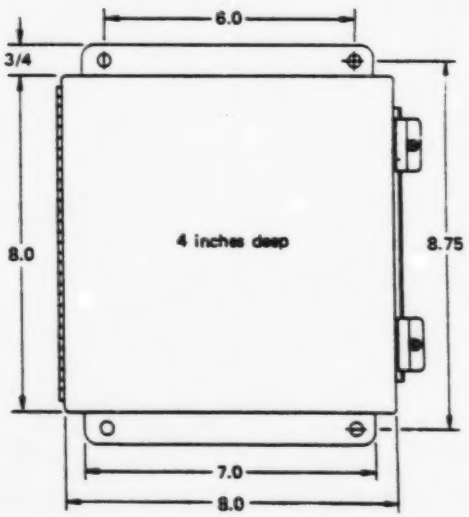
SCI1-12-BF3L

SCI1	12	A	Temperature Compensation
	24	B	Load Circuit Breaker (8)
	36	E	Adjustable Low-Volt Disconnect
	48	F1	Volt Meter/10 Amp Meter (8)
		F2	Volt Meter/20 Amp Meter (8)
		F3	Volt Meter/30 Amp Meter (8)
		H	Generator Start
		I	Array Power Diversion
		L	NEMA 13 Enclosure (8)
		M	NEMA 4 Enclosure
		N	Load Timer
		O	Low Power Relays
		P	50 Amp Charge Current

(8) Options B, F and L are standard for the PPC but must be included in part number.

DIMENSIONS

(in inches)



Specifications and product availability subject to change without notice.

SCI
9025 ETON AVE., SUITE D, CANOGA PARK, CA 91304 (818) 998-5238
TELEX 662914 SCI CNPK
SPECIALTY CONCEPTS, INC.

SBWD BATTERY INTERCONNECTS (8-1/2 In.) $5.14 EACH

T105 6 VOLT BATTERIES 74.00 EACH

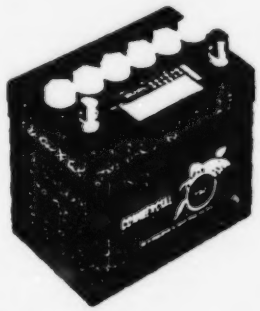
TROJAN BATTERY COMPANY

America's most dependable batteries since 1925

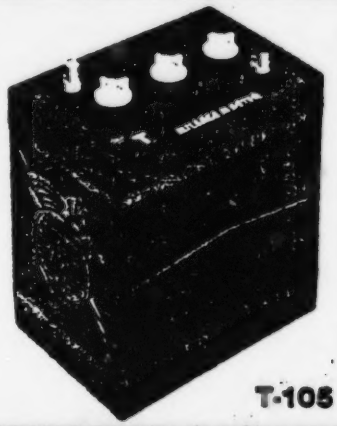
TROJAN MILEAGE MASTER BATTERIES

ENGINEERED AND ASSEMBLED ESPECIALLY FOR ELECTRIC VEHICLE USE

EV-27P



EV-7



T-105

TYPE	Units of Serv.	Quarts Acid	WEIGHT Wet	WEIGHT Dry	Ref. 20 Hr. Rate	Min. 75 Amps	OVERALL DIMENSIONS L	OVERALL DIMENSIONS W	OVERALL DIMENSIONS H	Pallet Qty.
SIX VOLT BATTERIES										
EV-2N	12	3.6	34	34	100	40	10	5-9/16	9	36
CS-1	12	3.7	40	29	120	48	9	6-7/8	8-5/8	36
CS-2	12	4	45	33	130	60	10-3/8	6-3/4	8-13/16	24
T-90	12	5.6	58	46	185	90	10-3/8	7-1/16	10-1/4	36
T-105	12	6	66	51	217	105	10-3/8	7-1/16	11-1/2	36
T-135	12	6.3	73	N.A.	244	135	10-3/8	7-1/16	11-1/2	36
J-250W	12	8	75	60	250	135	11-5/8	7	11-1/2	36
EV-7DS	12	7	70	52	215	100	16-1/4	7	9-1/4	24
EV-16	12	9	126	N.A.	350	187	11-11/16	7	16	18
TWELVE VOLT BATTERIES										
EV-7	12	3	20	15	30	—	7-3/4	5-3/16	7-1/4	70
EV-22NF	12	4	30	23	42	—	9-1/2	4-1/2	8-3/4	40
EV-24H	12	4.5	46	34	70	—	10-1/4	6-3/4	9-5/16	40
EV-24P	12	4.5	48	35	85	—	10-1/4	6-3/4	9-1/8	40
EV-29H	12	4.1	40	30	65	—	13	5-1/2	8-3/4	40
EV-27P	12	5.5	55	39	95	—	12	6-3/4	9-1/8	36
EV-30	12	6	69	54	105	—	13-1/2	6-13/16	9-1/4	36
EV-120	12	7.4	79	62	120	—	17-15/16	7-1/8	9-5/8	24
EV-12	12	8	92	69	140	—	16-1/2	7-1/8	11-1/4	24
EV-8D	12	14	168	127	240	—	20-3/8	10-15-16	9-1/2	12
GASOLINE ENGINE STARTING BATTERIES										
CS-22	12	4	32	24	55	—	9-1/2	6-13/16	8-3/8	40
HS-22	12	4	30	22	45	—	9-1/2	6-13/16	8-3/8	40
DS-24	12	4.6	36	24	41	—	10-1/4	6-3/4	8-3/4	40
HS-24	12	4.6	38	26	53	—	10-1/4	6-3/4	8-3/4	40
HS-3EE	12	5.6	46	30	62	—	19-1/4	4-5/16	8-3/4	40
HS-29NF	12	4.6	39	28	55	—	13	5-1/2	8-3/4	40

Batteries furnished with Automotive Posts, Angle Terminals, Wing Nut Terminals, or Universal Terminals—all at the same price.

Standard type lead coated bolts and nuts are included.

When ordering, specify as follows: A P (Automotive Posts); L T (Angle "L" Terminal); W T (Wing Nut Terminals); U T (Universal Terminals).

**For Universal Terminals or Angle Terminals, increase height one quarter inch.*

LIMITED WARRANTY

The manufacturer agrees to repair or replace at its option, for the original user, f.o.b. Factory, or at any authorized Service Station without charge except transportation, any battery of its manufacture which fails to give satisfactory service within 90 days from date of sale to the original user. The manufacturer further agrees after expiration of the 90 day guarantee period, to replace with a new battery on a pro rata basis, for the original user, any battery which fails in normal service.

LIMITATIONS: This warranty does not cover failure in service due to fire, wreckage, explosion, freezing, abuse, neglect, the use of a smaller size or capacity battery than installed by the vehicle manufacturer as original equipment. Nor does it cover damage from installation of the battery in reverse or recharging in reverse and breakage of containers, covers, or terminal posts. The cost of transportation, service calls, battery installations, recharges, or the use of rental batteries is not covered by this warranty.

Wm. LAMB CO.

heart interface T.M.

ULTRA-HIGH EFFICIENCY DC - AC POWER INVERTERS

THE 12 VOLT, 1200 WATT F.E.T. INVERTER

MODEL HF12-1200U

COMPARE THESE SPECIFICATIONS BEFORE YOU INVEST IN AN INVERTER!

- Less than one watt idling loss amp @ 12 volts)
- Quiet operation & compact design
- Regulated RMS voltage and frequency
- Adjustable charge voltage on Standby models
- Modified Sine Wave output
- Anodized aluminum and Stainless Steel construction
- Low cost

ULTRA-HIGH EFFICIENCY

This unit features the highest efficiency ever achieved for a 12 volt power inverter. Reaching 93% at 200 watts, and maintaining ultra-high efficiency throughout the power range.

HIGH MOTOR STARTING SURGE

The HF12-1200U is capable of 3500 watt surges, making it perfect for most small microwave ovens, refrigerators, and washing machines.

45 AMP BATTERY CHARGING STANDBY OPTION

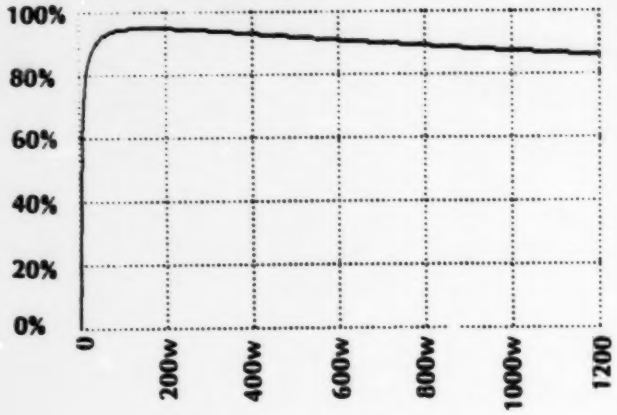
When Public Power or an AC generator is available, the unit operates as an automatic battery charger, while transferring all the loads to the incoming AC line. When the AC incoming is disconnected, the unit returns to the inverter mode. This Standby unit features adjustable battery charge voltage.

HEART INTERFACE CORP. 811 1ST AVE. S., KENT, WA 98032, TELEX 160563 HEART UT, TELEPHONE (206) 859-0640

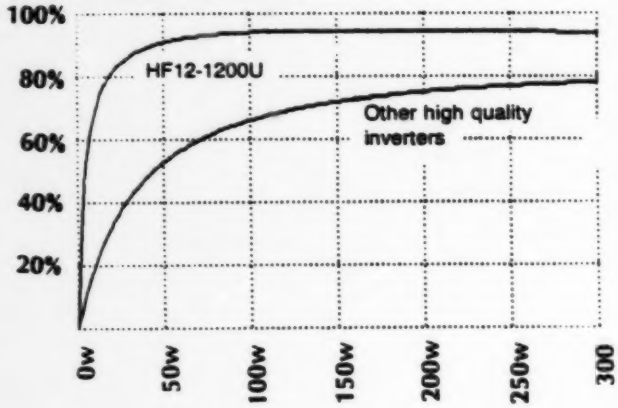
SPECIFICATIONS
MODEL HF12-1200U

Battery Voltage	12 Volts
Output Power	1200 Watts
Output Amperage	10 Amps
Output Voltage	120 V.A.C.
Battery Voltage Range	10.8 to 14.5 Volts
Voltage Regulation	2% true RMS
Frequency Regulation	.5% at 60 Hz.
No Load Power Drain	.8 Watt
Automatic Load Demand	Standard, no time delay
Waveshape	Modified Sine Wave
Power Factors	1 to .1 lagging
Low Battery Cutout	10.5 Volts
Dimensions	12.3" X 15" X 7.3"
Weight	42 lbs.
Warranty	1 year
X Model Surge	3500 watts
X Model adds to price	Standard
Standby Option	HF12-1200SU
Charging Rate	45 Amps
Initial Charge Voltage	14.3 Volts adjustable
Maintenance Charge Voltage	13.25 Volts adjustable
Protection	Circuit breaker Electronic overload Thermal overload High battery cut-out Low battery cut-out

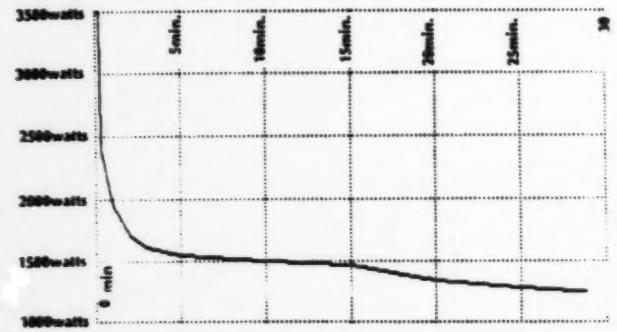
Efficiency v.s. output power for HF12-1200U inverters.



Efficiency v.s. output power for HF12-1200U and other inverters



Output power v.s. time until automatic shutdown for HF12-1200U



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